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Studies of Si Strips Elastically Loaded in Bending

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Beamline(s): X20A

Introduction: Flexural loading techniques are employed in experimental elastic constant and fracture strength determinations of semiconductor materials as well as in synchrotron x-ray monochromator applications [1-3] . Four-point bending, a common loading configuration, attempts to induce a constant curvature and moment along a single, or principal, sample direction. The resulting displacement and stress profiles are typically computed using a beam or plate analytical solution. However, Si test structures and monochromators posses dimensions that often make it difficult to determine whether a beam or plate treatment is more appropriate [4-5]. While most textbooks indicate that the primary criterion used to differentiate between a beam and a plate is the structure's width-to-thickness ratio, quantitative ranges for this ratio are rarely specified. We revisited an analysis, originally carried out by Searle [6] and expanded on by Ashwell [7], that describes a parameter for differentiating between rectangular, constant cross-section beams and plates. We term this parameter, which is dependent on specimen width (b), thickness (t), and bending radius (R), the Searle Curvature Ratio: $b = b^2/(Rt)$. When a sample is loaded in bending along a single, primary direction, e.g. sample length, anticlastic bending will occur along the transverse direction, e.g. sample width, due to Poisson coupling. The amount of anticlastic bending that occurs influences the stress and strain state of the sample and determines whether the sample behaves as a beam or a plate [3,6].

Methods and Materials: Using an x-ray microdiffractometer at the X20A Beamline, we have investigated the effects of anticlastic bending by mapping the curvature over the entire surface of rectangular, elastically bent Si specimens.

Results: Consistent with Shell's model [7], our results show that for b < 5, anticlastic curvature is unhindered, and the sample behaves as a beam, whereas, for b > 60, anticlastic curvature is neutralized over the majority of the sample width, and the sample behaves as a plate with increased stiffness.

We also postulated that, for a beam sample in four-point bending, the rollers that are used for load application impose additional constraints on the specimen that affect the anticlastic specimen curvature and cause the specimen displacement and stress profiles to deviate from the pure beam bending case [8]. We have mapped both the principal and anticlastic curvatures of (100)-type Is beams possessing width: thickness ratios of 40:1 (b=1.3). We have quantified the amount of roller constraint and shown that the region over which the anticlastic specimen curvature is affected away from the roller is approximately five times the roller diameter. Consequently, for bending tests used to determine Poisson's ratio, if a region on the sample that is free from roller effects is not chosen, measurement errors as high as 46% can occur. Also, we have shown that, due to the anisotropy of single crystal Si, this roller-constraining effect depends on crystallographic orientation and is more pronounced when the principal bending axis lies along the <100> direction as compared with the <110> direction.

Based on experimental results obtained at the X20 Beamline, we have developed quantitative design rules for tailoring both the flexural rigidity and the anticlastic shape of bending samples.

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